Neuro-Nanotechnology Applications for The Diagnosis and Treatment of Speech Disorders

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The problem of neuropsychological characteristics of speech disorders and their classification, despite a significant number of studies, to date, remains insufficiently studied, leaving a wide range of questions of speech pathology in aphasia unanswered. The study of the structure of the process of understanding speech in normal conditions, as well as the psychological structure of its impairment in case of brain damage, is of great importance for such a branch of neuropsychology as recovery training of patients with local brain damage. Among the various aspects of aphasic disorders, the problem of purposeful rehabilitation of speech functions is of particular importance, both theoretical and practical. The purpose of the study of this article was to determine the most effective methods for diagnosing and restoring the speech comprehension function in patients with sensory aphasia. According to the results of the study, it was concluded that the restoration of speech comprehension in patients with

sensory aphasia is determined by the polymorphic structure of etiopathogenesis for topical, syndromic and functional disorders and is based on the translational potential from subcortical to cortical structures; from primary to secondary and tertiary structures of functional systems of phonetic and auditory-speech analyzers; with reliance on other analyzers involved in the functional system of phonetic perception with retrospective stimulation of brain areas that, for one reason or another, are functionally impaired. The authors of the article have proved that the success of the restoration of lost functions in the process of restoring speech comprehension in patients with sensory aphasia directly depends on the intensity of corrective and rehabilitation work, both in a hospital or a rehabilitation center, and independently.

Keywords: neuropsychological characteristics of speech impairment, Nanotechnology, sensory aphasia, rehabilitation, recovery, organic structure of the defect, compensation.

1. Introduction

The use of a comprehensive approach in the study of speech comprehension is also effective for correct understanding the general psychological laws of speech comprehension (Behroozmand et al., 2018; Mesulam et al., 2019). Neuropsychological research methods not only make it possible to confirm which regions of the brain are affected in case of a disease, but also, to a certain extent, determine the prognosis for the restoration of impaired speech functions, provided that special speech therapy sessions are carried out, and also explain the lack of the desired result in some cases (Crosson et al., 2019; Johnson et al., 2020). Aphasia in the acute and early recovery period is characterized by a degree of severity of the speech defect, its structure in the acute period is blurred, there is a volumetric neurodynamic component. Concomitant disorders negatively affect the recovery of activity and quality of life (Babieva & Grechina, 2017; Zhigulina, Skvortsova & Solovyova, 2019). In addition to speech defects, patients who have suffered a stroke or traumatic brain injury have a number of concomitant disorders: cognitive disorders (including attention deficit, memory loss, slowness of thinking and speed of mental processes, in some cases - dementia), emotional-volitional disorders (depression, aspontaneity, hypobulia, decreased motor and mental activity). The development of neuropsychopathological syndromes is possible (the "right hemisphere" syndrome, the "frontal" syndrome) (Shklovsky & Vizel, 2000). WHO has identified strokes as a particularly complex socially significant category of diseases in terms of the severity of the consequences and the risk of disability.

The methodological foundation of the study was made by the theoretical propositions of L.S. Vygotsky (1934) about the structure of the defect and localization of higher psychological functions as structural units of brain activity; by the concept of A.R. Luria (1963) and his followers (Akhutina, 1979; Shklovsky & Vizel, 2000; Tsvetkova, 2000; Shokhor-Trotskaya, 2002) about the disintegration of the higher mental functions of the brain that is caused by focal brain lesions due to the loss of one factor or another, about aphasia, as a complex systemic speech disorder, embracing various levels of speech organization and affecting the

course of all mental processes; the principles of the consistency of the language, the connection of speech with other aspects of mental development and an holistic approach to diagnosis and treatment (Vinarskaya, 2006; Levina, 2012; Khomskaya, 2010; Gerstenecker & Lazar, 2019; Krishnamurthy et al., 2021); psycholinguistic theories about the mechanisms of speech activity, about its generation and perception, the interaction of speech processes (Akhutina, 1979).

The interdisciplinary approach to the research problem included the study of the fundamental points of general psychology concerning the complex multi-level organization of speech activity, in particular, speech comprehension (Leontiev, 1976; Rubinstein, 1973), research in the field of neurological rehabilitation and restorative training for patients who have suffered a stroke or traumatic brain injury, developed by M.G. Khrakovskaya (2017), V.M. Shklovsky and T.G. Vizel (2005), T.G. Wiesel (2005), M.K. Shokhor-Trotskaya (2002); J.P. Johnson et al. (2021).

Aphasia is defined as a systemic speech disorder that develops in case of organic brain lesions and covers different levels of speech organization - all language levels of phonology: phonetics, vocabulary, grammar, including four components: 1) impairment of speech itself and verbal communication; 2) impairment of other mental processes; 3) personality change; 4) personal reaction to a disorder (O'Sullivan, Brownsett & Copland, 2019).

The location of the focus in sensory aphasia is on the posterior third of the superior temporal gyrus of the left hemisphere (41, 41 and 22 fields, Wernicke's zone).

The main mechanism underlying this defect is impairment of acoustic analysis and synthesis of speech sounds - auditory agnosia, manifested in a loss of phonemic hearing. Phonemic hearing impairment is a central defect in sensory aphasia.

Phonemic hearing impairments cause severe disorders of impressive speech - understanding.

The problem of impaired speech understanding in sensory aphasia is studied from different angles, but detailed consideration of the state of impaired speech understanding in acoustic-gnostic and acoustic-mnestic aphasia is required to deepen and do a more extensive analysis of the problem under study (Fridriksson & Hillis, 2021).

2. Materials and Methods

The practical study involved 12 patients with sensory aphasia, including 6 women and 6 men aged between 44 and 81, selected according to the following criteria: the presence of sensory aphasia as the leading syndrome of speech impairment after acute cerebrovascular accident (in the overwhelming majority of ischemic type) or, less often, TBI (traumatic brain injury); the early recovery period - from six months to two years from the moment of the disease (Table 1 and Table 2).

Table 1. Experimental group № 1 (EG № 1)

№	The patient	Age	Diagnosis
1	Patient 1	47	A moderate form of acoustic-gnostic aphasia
2	Patient 2	52	A moderate form of acoustic-gnostic aphasia
3	Patient 3	61	A mild form of acoustic-gnostic aphasia
4	Patient 4	81	A moderate form of acoustic-gnostic aphasia
5	Patient 5	51	A moderate form of acoustic-gnostic aphasia
6	Patient 6	45	A severe form of acoustic-gnostic aphasia

Table 2. Experimental group № 2 (EG № 2)

№	The patient	Age	Diagnosis
1	Patient 1	44	A moderate form of acoustic-mnestic aphasia
2	Patient 2	73	A moderate form of acoustic-mnestic aphasia
3	Patient 3	71	A severe form of acoustic-mnestic aphasia
4	Patient 4	56	A moderate form of acoustic-mnestic aphasia
5	Patient 5	65	A moderate form of acoustic-mnestic aphasia
6	Patient 6	60	A moderate form of acoustic-mnestic aphasia

A package of diagnostic methods was used in the study of structural and functional disorders in case of focal brain lesions, which was based on two main principles proposed by A.R. Luria (1974): the principle of analyzing regionally limited brain lesions and the principle of isolating those factors that underlie the entire complex disorders arising from focal brain lesions (Akhutina, 1979) and methods of mathematical statistics: Wilcoxon's W-test and Mann-Whitney U-test for comparative analysis of the degree of speech impairment in patients of two diagnostic groups: with acoustic-gnostic and acoustic-mnestic aphasia.

Tasks were selected aimed at assessing the impressive aspect of speech (speech comprehension, inability to understand the meaning of a word), inability to name objects, and evaluation of phonemic perception, taking into account the specifics of impaired speech understanding in patients with sensory aphasia: in patients with acoustic-gnostic aphasia, the structure of the defect is a disorder of phonemic hearing, which, in turn, causes a severe impairment of impressive speech - understanding, and in patients with acoustic-mnestic aphasia in the structure of the defect lies a disorder of the auditory-speech memory operation, leading to impaired understanding of speech and inability to understand the meaning of a word against the background of preserved phonemic hearing and the process of sound recognition.

The specifics of manifestation of sensory aphasia lie in the fact that it seldom occurs as an unrelated case in the role of an acquired lesion of the auditory regions located in the brain

and in 85 % of lesion cases several regions of the brain are involved that are responsible for diverse functions in the injured person's organism.

Creating aphasia therapy activities, the impairment of all the analytical systems of the brain, characteristic of patients with sensory aphasia, was taken into account, as well as the most frequent errors were differentiated when diagnosing patients with sensory aphasia:

- Literal paraphasias;
- Impairment of spontaneous and repetitive speech;
- Inability to understand the meaning of a word;
- Logorrhea;
- Emboli;
- Writing and reading disorders.

Ten trials were given for each exercise. The following aspects were noted during the test:

- preservation of speech,
- the degree of impaired oral speech understanding was revealed,
- impairment of phonemic perception,
- agrammatisms,
- verbal and literal perseverations,
- manifestations of inability to understand the meaning of a word,
- difficulties in understanding logical - grammatical and verbal constructions.

3. Result and Discussions

The generalized data of the results of the experimental group No. 1 are presented in Tab. 3 and in Figure 1.

Table 3. The study results of speech comprehension of the experimental group № 1 with acoustic-gnostic aphasia

Tasks	1	2	3	4	5	6	7	8	9	10
Patient 1	1,5	1,4	1,1	0,3	1,6	0,5	1,7	1,2	1,5	1,3
Patient 2	1,2	1,2	1	0,2	1,5	0,5	1,6	1,1	1,1	1,3
Patient 3	0,5	1,8	1,7	1,4	2,2	0,8	2,1	2,2	2,1	1,9
Patient 4	1,2	0,8	0,5	0,2	1,1	0,5	1,1	0,9	1,1	1,2
Patient 5	1,1	1,1	0,4	0,3	1,2	0,4	1,1	0,8	0,9	1,1
Patient 6	1	0,4	0,1	0,2	0,7	0,2	0,4	0,3	0,3	0,3

Mean value	1,08	1,11	0,75	0,43	1,38	0,48	1,33	1,08	1,16	1,18
Performance in %	36%	37%	25%	14%	46%	16%	44%	36%	38%	39%

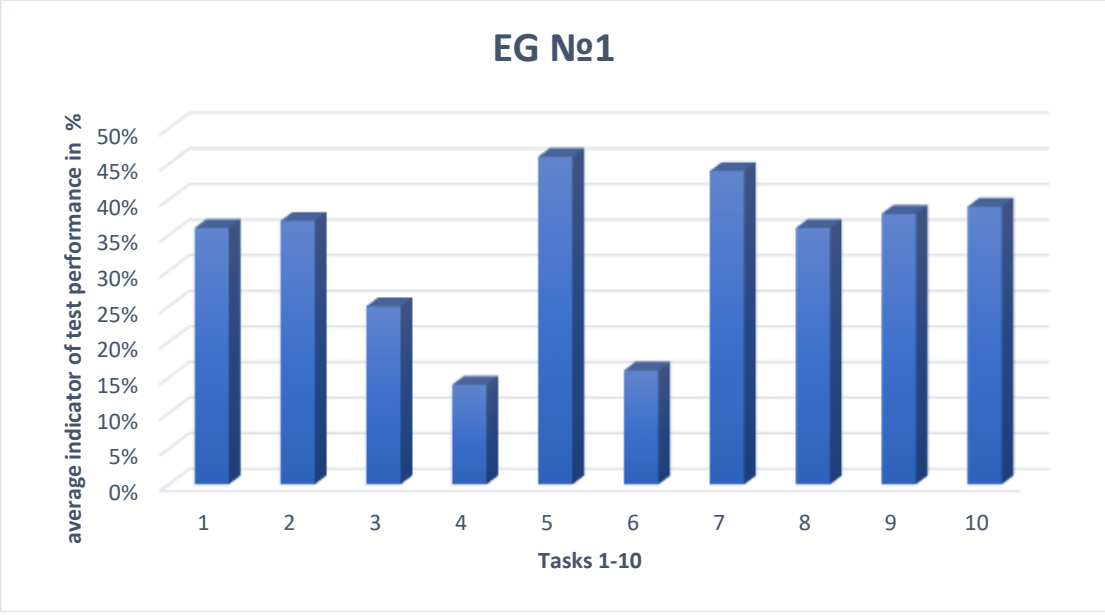

Figure 1. Average indicator of the diagnostic test performance in EG # 1 with acoustic-gnostic aphasia

Note: 1-10 blocks of Tasks: 1- Study of the general verbal communication ability; 2 - Study of the inability to name objects; 3 - Study of the automatic and repeated speech; 4 - Study of phonemic hearing; 5 - Understanding of verbal instructions; 6 - Study of auditory-speech memory ; 7 – Study of simple sentence comprehension; 8 – Study of understanding of logical-grammatical constructions; 9 – Study of understanding of comparative and inverted constructions; 10 – Study of comprehension of the meaning of a word

Figure 1 demonstrates the results of performing the tasks of the ascertaining experiment presented in Tab. 3: the average completion rate of the tasks by the experimental group.

The generalized data of the results on experimental group # 2 are presented in Tab. 4 and in Figure 2.

Table 4. Results of the study of speech comprehension of experimental group № 2 with acoustic-mnestic aphasia

Tasks	1	2	3	4	5	6	7	8	9	10
Patient 1	1,6	1,1	0,8	1,3	2	0,6	1,4	1,8	1,1	1
Patient 2	1,2	0,9	0,6	1,4	1,5	0,4	1,5	1,5	0,5	0,9

Patient 3	2,3	0,4	0,2	0,4	0,6	0,2	0,4	0,3	0,2	0,2
Patient 4	1,2	0,5	0,5	1,1	1	0,6	1,7	1,4	1	0,7
Patient 5	1,3	0,8	0,6	1,1	1,3	0,5	1,2	1,3	0,9	0,9
Patient 6	0,5	1,1	0,3	1	0,9	0,2	0,7	1	0,4	0,7
Mean value	1,35	0,8	0,5	1,05	1,21	0,41	1,15	1,21	0,68	0,73
Performance in %	45%	26%	16%	35%	40%	13%	38%	40%	22%	24%

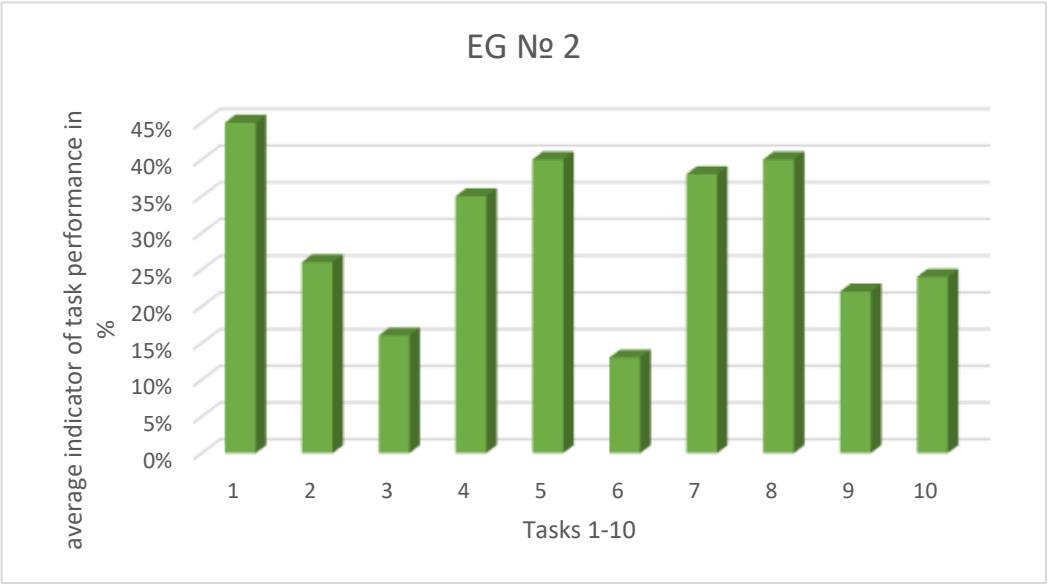

Figure 2. Average indicator of the diagnostic test performance in EG № 2 with acoustic-mnestic aphasia

To confirm sample representativeness, the Wilcoxon W-test was applied. For this sample, there were no statistically significant differences between the groups, therefore, the groups are homogeneous, and the experiment confirms the statistical reliability.

The use of the Mann-Whitney U-test makes it possible to determine the value of the criterion: the lower the value of the test, the more likely that the differences between the values of the parameter in the samples are reliable. Table 5 shows the found statistical differences in the examination results of patients in both experimental groups.

Table 5. The results of applying the criteria: Wilcoxon W-test and Mann-Whitney U-test based on the results of diagnostic examination

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_10
Mann-Whitney U-test	8,000	10,000	13,500	5,500	11,000	16,000	15,000	11,000	8,500	5,000
Wilcoxon W-test	29,000	31,000	34,500	26,500	32,000	37,000	36,000	32,000	29,500	26,000
Z	-1,607	-1,295	-,723	-2,027	-1,125	-,330	-,483	-1,129	-1,535	-2,093
Asymptotic significance (2-sided)	,108	,195	,470	,043	,261	,742	,629	,259	125	,036
Exact significance [2*(1-sided)]	,132	,240	,485	,041	,310	,818	,699	,310	,132	,041

Note:

	Level of significance p≤0.05
	Level of significance p≥0.05

In the course of the diagnostics between the two experimental groups, statistically significant differences were found when performing tasks 4 and 10.

These differences prove that there is a significant difference in the degree of speech impairment according to the diagnostic results between the two experimental groups - with acoustic-gnostic and acoustic-mnestic aphasia. The found differences indicate the specificity of the syndrome for each of the forms of aphasia and the presence of not only one central mechanism, as in acoustic-amnestic aphasia, but also several ones, as in the case of acoustic-gnostic aphasia:

1) In the form of acoustic-gnostic aphasia, disorders are especially manifested as impairment of phonemic hearing, differentiation of sounds and words similar in sound, with opposition phonemes, repeated pronunciation of words and auditory-speech memory.

2) In case of acoustic-mnestic aphasia, disorders are more manifested in the form of a decrease in the volume of auditory-speech memory during automatic and repeated speech, a decrease in the level of acoustic perception, impairment of understanding of comparative and inverted, logical-grammatical constructions.

Based on the conducted empirical study, the following conclusions were drawn: restoration of speech comprehension in patients with sensory aphasia is determined by the polymorphic structure of etiopathogenesis for regional, syndromic and functional disorders and is based on the progressive potential:

– from subcortical to cortical structures;

– from primary to secondary and tertiary structures in the functional systems of phonetic and auditory-speech analyzers;

– the use of other analyzers involved in the functional system of phonetic perception with retrospective stimulation of brain areas that, for one reason or another, are functionally impaired.

The rehabilitation work methods for patients with sensory aphasia were based fact that one of the most important features of the human brain - the ability to compensate underlies the restoration of impaired speech (Akhutina, 1979). Taking into account that there is direct and bypass compensation, it is possible to determine the presence of two main types of targeted impact on impaired speech:

Direct disinhibition methods of work are mainly used in the acute recovery period and are designed to activate reserve intra-functional capabilities.

Bypass methods imply compensation based on the restructuring of the impaired function itself due to interfunctional restructuring, that is, the recovery effect is achieved by introducing new, "bypass" ways of performing certain speech operations - both within one analyzer and with the involvement of other intact analyzer systems. A "bypass" of the defect can be achieved by replacing or rebuilding the impaired function. The inclusion of the affected activity with the help of spared afferentations suggests that later the function will start functioning in the normal mode (Tsvetkova, 2000).

At the same time, it is important to take account of the characteristics of each specific clinical case: the individual properties of the patient's personality, the severity of the somatic condition, case history, heredity and social environment in order to maximally motivate patients to participate in the rehabilitation process.

For a more effective restoration of speech comprehension in case of sensory aphasia, the principles of rehabilitation training were developed. The theoretical foundation of these principles is the existing contemporary ideas about the higher mental functions, their systemic dynamic localization and lifetime formation, the founder of which was L.S. Vygotsky (1934). These ideas were complemented by A.R Luria's (1963) idea of them as functional systems. The rehabilitation training program represented a process that included various methods and techniques aimed at restoring lost speech and non-speech functions, and was built taking account of the principle of consistency, that is, rehabilitation activity was carried out on all sides of the impaired function, and not only with those who suffered for the first time. As part of the implementation of this approach, the following tasks were consistently solved:

– recovery of speech as a mental function, rather than adaptation of the patient with aphasia to his defect;

– restoring the activity of verbal communication, and not isolated particular sensorimotor speech operations;

– restoring the communicative function of speech, rather than its individual aspects;

– the return of the patient with aphasia to a normal rather than simplified speech environment, ie. return to professional activity.

In case of acoustic-gnostic aphasia, the main task of correction was to overcome the defects in the differentiated perception of sounds, namely, to restore phonemic perception. Since numerous disorders in acoustic-gnostic aphasia are the cause that complicates the socialization and adaptation of a person - impairment of speech comprehension, the restoration of the sound recognition process will be able to provide a gradual revival of all affected sides of speech. Rehabilitation training in case of acoustic-gnostic aphasia was aimed at:

1. Making contact with the patient, translating the verbal method of communication into non-verbal activity, inhibiting the patient's verbosity (logorrhea) and shifting the speaker's attention from his own speech to a non-verbal form of activity;

2. Teaching "listening" and "hearing" of addressed speech;

3. Transition to conscious and differentiated selection of phrases from the text and words from a phrase;

4. Restoration of differentiated and constant perception of speech sounds, i.e., the activity to restore phonemic hearing.

In case of acoustic-mnestic aphasia, the primary task of rehabilitation training was purposeful work to restore stable visual images, to restore auditory-speech memory and expand the volume of acoustic perception. The key objective of rehabilitation training consisted in:

1. Making contact with the patient, restoring the subject reference of the word and visual-object representations. It is important to note that rehabilitation work in case of sensory aphasia begins not with speech therapy techniques, but with work in the main areas: the restoration of visual-object images using drawing and classification of objects, first according to the visual pattern, then, according to the word.

2. Restoring the process of recognition and naming objects with the help of: constructing objects from separate parts, comparing and finding common features and differences and detecting errors in the image.

3. Activities to restore repeated and reflected speech using the method of breaking down words, sentences and text into parts accessible to the patient's perception.

4. Restoring text comprehension using the method of composing a text from its separate semantic parts.

As a result of rehabilitation training, a positive trend was noted in patients in both experimental groups (Figure 3 and Figure 4).

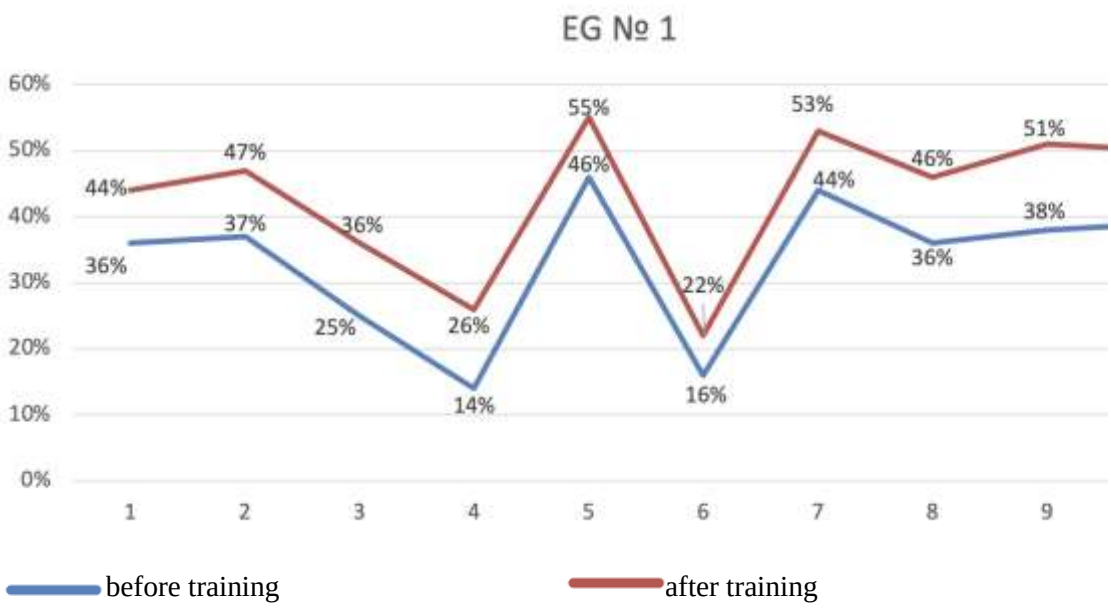

Figure 3. Restoration dynamics of speech comprehension in EG № 1 before and after rehabilitation training

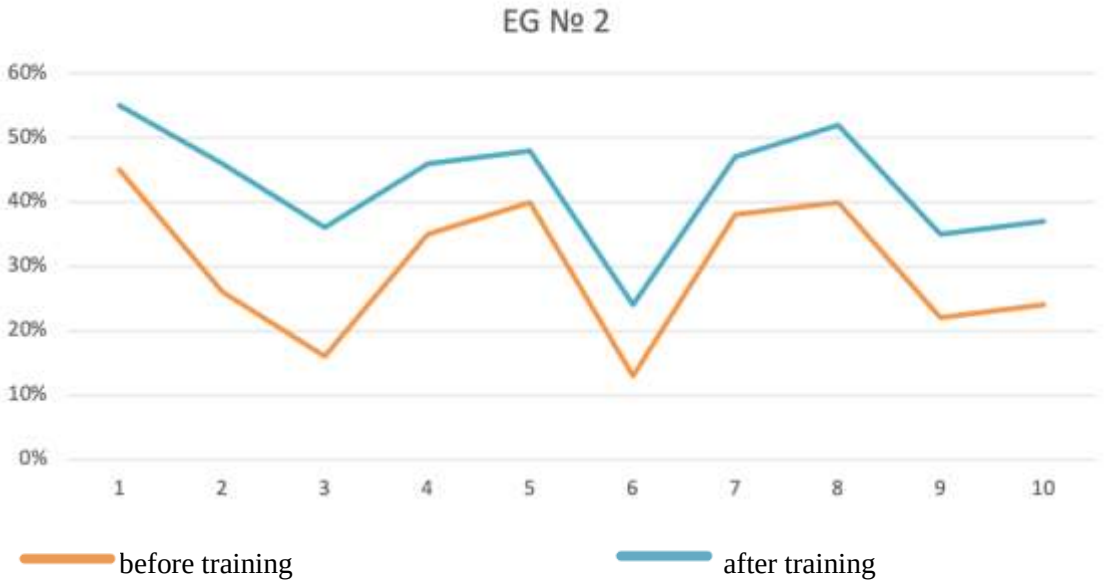

Figure 4. Restoration dynamics of speech comprehension in EG № 2 before and after rehabilitation training

To compare the values between EG № 1 and EG № 2 the Wilcoxon T-test was used. The results are presented in Table 6.

Table 6. Empirical values of the Wilcoxon T-test

Name of the scales	Mean value in EG № 1	Mean value in EG № 2	Empirical value of the test	Level of significance
Before training	0.998	0.909	37.0	0.333
After training	1.303	1.289	24.5	0.813

Level of significance $p \leq 0.05$

Level of significance $p \geq 0.05$

These differences prove a significant difference in the performance of tasks “Before” and “After” the training sessions, which assess the state of speech comprehension in patients with sensory aphasia.

4. Conclusion

Based on the conducted empirical study, the following conclusions can be drawn: the reasons for the differentiated distinction, as well as the similarity of the manifestation in the early recovery period of impaired speech comprehension between the acoustic-gnostic and acoustic-mnestic forms of aphasia and the features of the manifestation of impaired speech comprehension in patients with sensory aphasia are due to the primary defect which underlies the dysfunction of phonemic hearing or auditory-speech memory, which have a focal nature of the lesion, leading to secondary manifestations of a disorder of the central mechanisms of intellectual functions and, as a consequence, determining the characteristics of a speech defect. The degree of manifestation of impaired understanding is determined, first of all, by the location of the lesion: in acoustic-gnostic aphasia, these are fields 41, 42 and 37, in acoustic-amnestic aphasia, these are fields 37 and 21, and largely depends on the etiology and duration of the disease.

Thus, the success of the recovery of lost functions in the process of restoring speech comprehension in patients with sensory aphasia will directly depend on the intensity of further correction and rehabilitation work, both in a hospital or a rehabilitation center, and independently, with the participation of relatives, or in a remote format of rehabilitation classes.

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